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A NEW MEASUREMENT OF $\Sigma^+ \rightarrow p\gamma$ DECAY PROPERTIES^(†)

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ABSTRACT

We have measured the asymmetry parameter α_γ for the decay $\Sigma^+ \rightarrow p\gamma$ to be $\alpha_\gamma = -0.53^{+0.38}_{-0.36}$. For the branching ratio we find $\Gamma(\Sigma^+ \rightarrow p\gamma)/\Gamma(\Sigma^+ \rightarrow p\pi^0) = (2.11 \pm 0.38) \times 10^{-3}$. The experiment was performed using the HYperon BUBble Chamber (HYBUC) at the CERN PS.

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The only previous measurement [1] of α_Y , the asymmetry parameter for the decay $\Sigma^+ \rightarrow p\gamma$, found the value $\alpha_Y = -1.03 \pm 0.52$. To explain this result has been a challenge for models [2] on hadronic weak interactions, since the standard assumptions (see for example Hara) require the parity violating amplitude to vanish and therefore $\alpha_Y = 0$. The interest in the radiative decays of hyperons comes from the fact that they can provide a key for understanding the non-leptonic weak interaction. In this letter we describe a new measurement of α_Y using the HYperon BUbble Chamber (HYBUC).

Previous measurements of the branching ratio $\Gamma(\Sigma^+ \rightarrow p\gamma)/\Gamma(\Sigma^+ \rightarrow p\pi^0)$ vary between 11.0×10^{-3} and 0.7×10^{-3} , the world average being $(2.40 \pm 0.35) \times 10^{-3}$ [3]. We have also obtained a new estimate for this branching ratio.

HYBUC was built for a precision measurement of the Σ^+ magnetic moment μ_{Σ^+} [4]. HYBUC is a hydrogen bubble chamber cylindrical in shape, 11 cm in diameter and 32 cm long, and situated in a 115 kG superconducting solenoid; details of the hardware have been published elsewhere [4,5]. We recall one unconventional feature of the hardware here, namely that the beam enters the chamber parallel to the magnetic field and optical axes. HYBUC was exposed to $\sim 1.5 \times 10^7$ K^- in 2×10^6 pictures at the CERN proton synchrotron. The Σ^+ were produced in the reaction $K^- p \rightarrow \Sigma^+ \pi^-$ at beam momenta ranging from 420 to 500 MeV/c; in this range the Σ^+ are highly polarized. In the course of the experiment, we have separated a sample of $\Sigma^+ \rightarrow p\gamma$ decays out of the total sample of Σ^+ events used for the μ_{Σ^+} determination.

The film was scanned twice for 2-prong $V^\pm$ topologies, the overall scanning efficiency being better than 98%, assuming random losses. All $\Sigma^\pm$ candidates were measured on image-plane or film-plane digitizers, and the events were reconstructed using the HYDRA geometry-kinematics program chain [6]. The events were then reexamined on the scanning tables to decide on track ionization, and the ones failing to give a multivertex fit in agreement with the ionization decision were recycled through the measurement-reconstruction procedure. Events which still failed were recycled again. The residual failure rate after all of this was less than 5%, of which a subsequent study showed less than 10%, i.e. $< 0.5\%$

of the total, to be two-body Σ^+ events of the type $K^- p \rightarrow \Sigma^+ \pi^-$. The final sample contained a total of 35 832 $\Sigma^+ \rightarrow p$ decays.

The main problem for the present study is the separation of the $\Sigma^+ \rightarrow p\gamma$ and the $\Sigma^+ \rightarrow p\pi^0$ decays, which are kinematically similar, the latter being a few hundred times more frequent than the former. We show that separation is achieved by discriminating on the missing mass squared at the decay vertex, MM^2 (in the bubble chamber the neutral decay particle is not seen).

After reconstruction, a Σ^+ candidate can make a multivertex fit to one or more of the hypotheses

Types (a) or (b) can be distinguished from each other and from (c) and (d) by the track ionization (for type (b) one also looks for a recoil proton at the secondary vertex). Events of type (c) and (d) can be separated in principle on the basis of their MM^2 . For (c), $MM^2 = 0.0182 \text{ GeV}^2$, and for (d), $MM^2 = 0.0 \text{ GeV}^2$, so that in practice the efficiency of this separation depends on δMM^2 , the measuring error of MM^2 , being small enough for a given ratio of the two decay rates.

On the average, the measuring error in our experiment is $\delta MM^2 \approx 0.005 \text{ GeV}^2$, as is seen in fig. 1(a). The histogram shows the δMM^2 distribution for the $\Sigma^+ \rightarrow p\pi^0$ sample, which was cleaned up by the following cuts: the event had to be within a fiducial volume extending from 2 cm from the entrance to 6 cm from the exit of the chamber to make sure of having enough track length to measure the event well; the missing mass between the beam track and the π^- from the production vertex had to be between 1.15 GeV and 1.23 GeV to establish the event as a clear case of two-body Σ^+ production, and the probability for the overall multivertex fit had to be better than 2% to ensure that the measurements and kinematics are compatible for the whole event. After these cuts there were 25 763 events in the sample. The average MM^2 error for these events is $\langle \delta MM^2 \rangle = 0.0051 \text{ GeV}^2$.

Since the difference in MM^2 between the $\Sigma^+ \rightarrow p\pi^0$ and $\Sigma^+ \rightarrow p\gamma$ decays is 0.0182 GeV^2 , the two channels are better than three standard deviations apart in MM^2 on the average. If the MM^2 distributions (shown below) is gaussian, then for $\delta MM^2 = 0.005 \text{ GeV}^2$, the tail from the $\Sigma^+ \rightarrow p\pi^0$ sample at the MM^2 for $\Sigma^+ \rightarrow p\gamma$ is at the level of 10^{-3} . Thus the two decay modes can be separated in this experiment, as long as $\Gamma(\Sigma^+ \rightarrow p\pi^0)/\Gamma(\Sigma^+ \rightarrow p\gamma)$ does not exceed the order of 10^3 .

Here we have discussed the use of MM^2 and its average error to emphasize the plausibility of separating the $\Sigma^+ \rightarrow p\gamma$ channel from our data. The actual separation procedure for this channel is slightly more complicated than these arguments might indicate, and is described below. The procedure does depend on the measurements and their errors being reliable, and we address ourselves to this point first.

The MM^2 and its error δMM^2 are calculated by the HYDRA geometrical reconstruction program. Although it is straightforward to determine MM^2 , in the past the calculation of δMM^2 in bubble chamber geometry programs has been fraught with problems. However, our geometry and kinematics programs have been set up and tuned to do a complete and correct error analysis of each event. The full error matrix including all correlations between track parameters is computed internally in the geometry program from the distribution of measured points about the fitted tracks, and this error matrix is passed to the kinematics programs where it is used in computing δMM^2 and in fitting the hypotheses. The reliability of the error handling is shown in fig. 2, where the r.m.s. spread of the MM^2 distribution for events of a given δMM^2 is plotted as a function of δMM^2 for the $\Sigma^+ \rightarrow p\pi^0$ sample. The measured points lie very close to the ideal situation indicated by the dashed line at 45° . Thus δMM^2 is correct up to 0.010 GeV^2 , beyond which the events are not used in this analysis, as will now be seen.

We have separated out the $\Sigma^+ \rightarrow p\gamma$ events in our sample in two stages. In the first stage we selected those events which gave an acceptable kinematic fit uniquely to hypothesis (d) above, and this unique $\Sigma^+ \rightarrow p\gamma$ fit had to survive at least two measurement cycles. Since this stage

found mainly those events for which δMM^2 was very small, we used a second stage in which events with small MM^2 , but not necessarily with small δMM^2 , were measured five times. Those events were admitted to the $\Sigma^+ \rightarrow p\gamma$ sample which consistently had a low MM^2 and a factor of 10 better fit probability to the $\Sigma^+ \rightarrow p\gamma$ hypothesis than to the $\Sigma^+ \rightarrow p\pi^0$ hypothesis. We now explain these two stages in more detail.

For the first stage, after all events had been cycled through the normal measurement-reconstruction procedure as described above, we began by selecting those events for which (d) was the only hypothesis to give a fit (each of the other hypotheses was considered not to fit the event if the χ^2 probability was $< 10^{-4}$). These events were reexamined on the scanning table to check that the decay particle was a proton and that there was nothing "pathological" about the event (e.g. that the beam was not off-axis, that the decay track did not have a large multiple scatter, etc.). The events which survived this inspection were measured again, and those which still fitted uniquely the $\Sigma^+ \rightarrow p\gamma$ hypothesis were kept in the sample. Towards the end of the analysis of the Σ^+ magnetic moment experiment, after we had introduced the last refinements into the reconstruction programs, we passed all events through the programs a final time. The $\Sigma^+ \rightarrow p\gamma$ events were again required to give a unique fit.

For the second stage all events (excluding those from the first stage) with (a) a proton decay particle, (b) $MM^2 \leq 0.010 \text{ GeV}^2$, and (c) $\delta MM^2 \leq 0.015 \text{ GeV}^2$ were measured five times. Here possibly misidentified $\Sigma^+ \rightarrow n\pi^+$ events were examined if they also fit the $\Sigma^+ \rightarrow p\gamma$ hypothesis and measured if they fulfilled these criteria. The measurements had to be "good", meaning residuals in space on fiducial mark, vertex, and track reconstruction had to be $< 100 \mu\text{m}$. An event which could not be measured well five times in up to ten trials was considered unmeasurable. As mentioned above, unmeasurable two-body events, after the normal measurement-reconstruction procedure, are $< 0.5\%$ of the total sample; here we wanted to avoid feeding those low quality events into the $\Sigma^+ \rightarrow p\gamma$ sample. The events for which all five measurements gave $MM^2 < 0.010 \text{ GeV}^2$, $\delta MM^2 \leq 0.010 \text{ GeV}^2$ and the kinematic fit probability a factor 10 better for the hypothesis $\Sigma^+ \rightarrow p\gamma$ than for $\Sigma^+ \rightarrow p\pi^0$, were admitted to the $p\gamma$ sample.

The last requirement on the events before they could be used in measuring the $\Sigma^+ \rightarrow p\gamma$ decay characteristics was that the kinematic fit have a probability $> 2\%$, so that the measured and fitted quantities were compatible for the entire event. After this procedure, the final $\Sigma^+ \rightarrow p\gamma$ sample contained 46 events, 35 of which were found in the first stage and 11 in the second.

For these 46 $\Sigma^+ \rightarrow p\gamma$ events, the distribution of δMM^2 is plotted in fig. 1(b). One sees that it was possible to separate out $\Sigma^+ \rightarrow p\gamma$ events with δMM^2 larger than 0.005 GeV^2 , which, as discussed above, δMM^2 should be equal to or less than in order to have the $\Sigma^+ \rightarrow p\pi^0$ and $\Sigma^+ \rightarrow p\gamma$ signals be at least three standard deviations apart in MM^2 . This was possible because, as observed in the previous experiment [1], for $\Sigma^+ \rightarrow p\gamma$ the proton can decay at an angle which is larger than kinematically allowed for $\Sigma^+ \rightarrow p\pi^0$, and such events can fit uniquely $\Sigma^+ \rightarrow p\gamma$ even with a larger δMM^2 . Also the procedure of measuring the $\Sigma^+ \rightarrow p\gamma$ candidates several times effectively eliminated large statistical fluctuations, making it possible to find events with $\delta MM^2 > 0.005 \text{ GeV}^2$.

To determine the $\Sigma^+ \rightarrow p\gamma$ decay properties we must know how they are biased by losses in the $\Sigma^+ \rightarrow p\gamma$ sample. Bias has been introduced by the selection procedure: events with large δMM^2 are lost. The δMM^2 depends on several characteristics at the decay; examples are the momentum, angle, and track length of the decay proton and the magnetic field at the event. For instance, the larger the decay proton momentum, the larger the measuring error on this momentum, and thus the larger the δMM^2 . Therefore the selected $p\gamma$ sample shows a depletion of events with proton momentum larger than $\sim 400 \text{ MeV/c}$. This loss in turn biases the decay angular distribution in the rest frame of the Σ^+ .

It will be demonstrated below (fig. 4) that the losses present in the $\Sigma^+ \rightarrow p\gamma$ distributions can be reproduced in the $\Sigma^+ \rightarrow p\pi^0$ sample simply by cutting out $\Sigma^+ \rightarrow p\pi^0$ events with large δMM^2 . The $\Sigma^+ \rightarrow p\pi^0$ decay properties are then correspondingly biased, and the amount of bias is known since the unbiased $\Sigma^+ \rightarrow p\pi^0$ decay properties are known. Our assumption from now on is that for a given δMM^2 cut on both samples the fractional biases are the same for the decay properties of the $\Sigma^+ \rightarrow p\gamma$ sample as for those of the $\Sigma^+ \rightarrow p\pi^0$ sample. The measured $\Sigma^+ \rightarrow p\gamma$ parameter can then be corrected for its bias simply by multiplying it by the ratio of the unbiased value to the biased value for the $\Sigma^+ \rightarrow p\pi^0$ sample.

That this method for estimating the bias in the $\Sigma^+ \rightarrow p\gamma$ sample is approximately correct is intuitively clear because of the kinematic similarity of the $\Sigma^+ \rightarrow p\pi^0$ and $\Sigma^+ \rightarrow p\gamma$ decay channels. We have verified this approach using a Monte-Carlo simulation of the two decay channels, introducing a given loss in both channels, and then seeing that the decay parameters are biased by about the same fractional amount. We have also studied the problem by using a weighting procedure to correct the $\Sigma^+ \rightarrow p\gamma$ angular distribution and found a bias of the same order as the above-described methods. All these approaches agree that the bias in the decay asymmetry parameter α_γ is always less than $\sim 10\%$, which is small compared to the statistical error.

Many $\Sigma^+ \rightarrow p\pi^0$ events with large δMM^2 have already been eliminated by the cuts explained above on fiducial volume, missing mass at production, and multivertex fit probability. The only other cut we now introduce is in δMM^2 . If we accept only events with $\delta MM^2 \leq 0.005 \text{ GeV}^2$ in both the $\Sigma^+ \rightarrow p\pi^0$ and $\Sigma^+ \rightarrow p\gamma$ samples, then the MM^2 distribution shown in fig. 3 results. As discussed above, a value of $\delta MM^2 \leq 0.005 \text{ GeV}^2$ should allow separation of the $\Sigma^+ \rightarrow p\gamma$ signal from the $\Sigma^+ \rightarrow p\pi^0$ events in the MM^2 plot, and we see from fig. 3 that this is indeed the case. We first determine the corrected $\Sigma^+ \rightarrow p\gamma$ decay parameter using these reduced samples and then show that this parameter is insensitive to the δMM^2 cut.

The decay angular distribution is

$$\frac{1}{N} \frac{dN}{d\Omega} = \frac{1}{4\pi} (1 + \alpha \vec{P} \cdot \hat{p}) \quad (1)$$

where N is the number of events, Ω is the solid angle, α is the decay asymmetry parameter, $\vec{P}$ is the polarization at the point of decay, and $\hat{p}$ is a unit vector in the proton direction in the Σ^+ rest frame. This angular distribution is shown in fig. 4 for the two samples with $\delta MM^2 \leq 0.005 \text{ GeV}^2$. The distribution should vary linearly with $\vec{P} \cdot \hat{p}/|\vec{P}|$ and with slope determined by αP . The depletion of events in the range -0.5 to $+0.5$ is a consequence of the δMM^2 cut and the HYBUC geometry [7].

That is, because the beam enters along the magnetic field axis, the polarization is perpendicular to this axis. The decay protons emitted along the field direction are thus perpendicular to the polarization, so that $\vec{P} \cdot \hat{p} \approx 0$. Protons emitted along the field direction have large momentum errors, so that such events have large δMM^2 and are rejected by the δMM^2 cut. There is also a $\sim 7\%$ scanning loss around $\vec{P} \cdot \hat{p} \approx 0$ coming from events having too small a decay angle to be seen [4]. The combined scanning and δMM^2 cut losses are seen from fig. 4 to be qualitatively the same, as was discussed above. We now describe the measurement of α_Y .

Due to the Σ^+ magnetic moment, the polarization precesses in the magnetic field. Projecting the angular distribution (1) onto the plane of precession, we have [4]

$$\frac{1}{N} \frac{dN}{d\phi} = \frac{1}{2\pi} \left[1 + \frac{\pi}{4} \alpha P \cos(\phi - \phi_0) \right], \quad (2)$$

where ϕ is the angle between the projection of $\hat{p}$ onto this plane and the direction which the polarization would have if the Σ^+ had zero anomalous magnetic moment, $\mu_a \approx 0$, and ϕ_0 is the precession angle due to the Σ^+ anomalous magnetic moment.

We use the maximum likelihood method to determine α , the likelihood function L_i for event i being taken from eq. (2)

$$L_i = 1 + \frac{\pi}{4} \alpha P_i \cos(\phi_i - \phi_{0i}). \quad (3)$$

The polarization P_i for each event is calculated from the π^- production angle using the coefficients found in a $K^- p$ partial wave analysis [8], the results of which fit our data very well [7, 9]. The precession angle ϕ_{0i} is calculated for each event using $\mu_a = +1.91$ i.m. from our Σ^+ magnetic momentum measurement [4]. The best estimate of α for a sample of events is that value for which $\sum \ln L_i$ is a maximum, and the error corresponds to the value of α at which this sum decreases by 0.5 from the maximum.

Fitting α_Y in this way to the decay angular distribution of the 35 $\Sigma^+ \rightarrow p\gamma$ events in fig. 4(b) gives $\alpha_Y = -0.55 \pm_{-0.39}^{+0.42}$. Fitting α_0 to the decay angular distribution of 17 354 $\Sigma^+ \rightarrow p\pi^0$ events in fig. 4(a) gives $\alpha_0 = -1.084 \pm 0.016$. Since $\alpha_0 = -1$ was assumed in the partial wave analysis [8], then α_0 is overestimated by $\sim 8\%$ due to the δMM^2 cut. Correcting α_Y by this amount, the value for the reduced $\Sigma^+ \rightarrow p\gamma$ sample becomes $\alpha_Y = -0.51 \pm_{-0.39}^{+0.42}$.

If we relax the δMM^2 cut to $\delta MM^2 \leq 0.009 \text{ GeV}^2$, all 46 $\Sigma^+ \rightarrow p\gamma$ events and 23 183 $\Sigma^+ \rightarrow p\pi^0$ events are accepted. The separation of the two signals on the MM^2 plot is not quite as clear as in fig. 3. The shape of the $\Sigma^+ \rightarrow p\gamma$ distribution in MM^2 does not change much since these events have been carefully selected. The tail from the $\Sigma^+ \rightarrow p\pi^0$ events increases in the $\Sigma^+ \rightarrow p\gamma$ region since the $\Sigma^+ \rightarrow p\pi^0$ events have not been carefully selected, the majority having been measured only once. The decay parameters are hardly affected; we find now $\alpha_Y = -0.56 \pm_{-0.36}^{+0.38}$, and $\alpha_0 = -1.054 \pm 0.015$. The value for α_0 shows that the bias due to the δMM^2 cut is now less since we have a more complete sample. Otherwise the parameters have stayed the same, and we have verified that this is true for all δMM^2 cuts between $\delta MM^2 \leq 0.004 \text{ GeV}^2$ and $\delta MM^2 \leq 0.009 \text{ GeV}^2$. For cuts in δMM^2 smaller than 0.004 GeV^2 , there are not enough $\Sigma^+ \rightarrow p\gamma$ events left to determine α_Y reliably, and we do not try larger cuts than 0.009 GeV^2 since there are no $\Sigma^+ \rightarrow p\gamma$ events above this value.

For the final value of α_Y , we again correct by the ratio of the value of α_0 assumed for the partial wave analysis to the value of α_0 biased by the $\delta MM^2 \leq 0.009 \text{ GeV}^2$ cut. The final value becomes

$$\alpha_Y = -0.53 \pm_{-0.36}^{+0.38} \quad (4)$$

To determine the branching ratio, we use a δMM^2 cut for which the two signals on the MM^2 plot separate completely. This occurs for the cut $\delta MM^2 \leq 0.004 \text{ GeV}^2$, as seen by the dashed line in fig. 3. This cut reduces the samples to 30 $\Sigma^+ \rightarrow p\gamma$ events and 14 239 $\Sigma^+ \rightarrow p\pi^0$ events, so

$$\frac{\Gamma(\Sigma^+ \rightarrow p\gamma)}{\Gamma(\Sigma^+ \rightarrow p\pi^0)} = (2.11 \pm 0.38) \times 10^{-3} . \quad (5)$$

This ratio also turns out to be the same, well within errors, for all δM^2 cuts between $\delta M^2 \leq 0.004 \text{ GeV}^2$ and $\delta M^2 \leq 0.009 \text{ GeV}^2$. We quote the value (5) as our final one for the branching ratio since separation of the signals in M^2 avoids any discussion about background subtraction.

The effect of background on the measurement of α_Y has been our main concern in studying the data. If the $\Sigma^+ \rightarrow p\gamma$ sample contained a $\Sigma^+ \rightarrow p\pi^0$ background with asymmetry of the same magnitude as found for α_Y , it could have influenced the result. Our confidence in the purity of the $\Sigma^+ \rightarrow p\gamma$ sample is based on three points: (i) each $\Sigma^+ \rightarrow p\gamma$ event was selected carefully. The candidates were measured several times: two to three times in the first stage and five or more times in the second stage. The final selection criteria were conservative to ensure negligible background. (ii) The result for α_Y is independent of the δM^2 cut. For $\delta M^2 \leq 0.004 \text{ GeV}^2$, the two signals in M^2 separate (dashed line, fig. 3) and any $\Sigma^+ \rightarrow p\pi^0$ background in the $\Sigma^+ \rightarrow p\gamma$ sample is evidently eliminated in this case. The value of α_Y for this cut after correction for bias is $\alpha_Y = -0.52 \pm 0.41$. This result compared with the ones stated above for other cuts indicates that the $\Sigma^+ \rightarrow p\gamma$ contains very little background. (iii) Events which fit both $\Sigma^+ \rightarrow p\gamma$ and $\Sigma^+ \rightarrow p\pi^0$ hypotheses but which do not satisfy the stringent $\Sigma^+ \rightarrow p\gamma$ selection criteria have quite different physical characteristics from either of the pure $\Sigma^+ \rightarrow p\gamma$ or $\Sigma^+ \rightarrow p\pi^0$ samples (i.e., with δM^2 cuts). In particular, the angular distribution in fig. 4 for these "ambiguous" events peaks at $\vec{p} \cdot \hat{p}/|\vec{p}| \sim 0.0$ and drops sharply at $\sim \pm 1.0$.

Combining the results (4) and (5) with previous measurements, the world averages become

$$\alpha_Y = -0.70 \pm 0.31 \quad (6)$$

and

$$\frac{\Gamma(\Sigma^+ \rightarrow p\gamma)}{\Gamma(\Sigma^+ \rightarrow p\pi^0)} = (2.26 \pm 0.26) \times 10^{-3}. \quad (7)$$

The upper (positive) errors were used for computing the weighted mean α_Y .

This new value (6) for α_Y still indicates that the parity violating amplitude is of the same order as the parity conserving one. The many attempts from 1971 on [2] to explain a large parity violating amplitude can be divided roughly into two types. In the first type it is assumed that strong interactions cause the effect, and in the second type it is assumed that the hadronic weak interaction must be amended. Strong interaction effects have been included using current algebra (see e.g. Holstein) or dispersion relations (see e.g. Ferrar). The hadronic weak interaction has been modified by the postulation of right-handed currents coming into the quark decay (see e.g. Ahmed and Ross) or the proposal that W exchange between two quarks might be important (see e.g. Picek).

This is hardly the place for a detailed evaluation of these theories. They have varying success with α_Y : models on strong interaction effects tend to predict smaller absolute values, models modifying the hadronic weak interaction are sensitive to the structure assumed for it. All theories seem to give a reasonable decay rate. However, it should be mentioned that the proposal of W exchange between two quarks was already made because single quark decay predicts the wrong relative rates for Σ^+ and Ξ^0 radiative decays (see Gilman and Wise).

We note finally that our result is in good agreement with that of Gershwin et al. [1]. Our result (4) alone probably would not have provoked so much speculation, since within errors it indicates that the parity violating amplitude could be small.

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FIGURE CAPTIONS

- Fig. 1 Distribution of δMM^2 , the error on the missing mass squared at decay, for (a) the $\Sigma^+ \rightarrow p\pi^0$ sample and (b) the $\Sigma^+ \rightarrow p\gamma$ sample.
- Fig. 2 The root-mean-squared width of the decay missing mass squared distribution as a function of δMM^2 (the error in decay missing mass squared) as calculated in the HYDRA program for each event. The data fall close to the ideal case shown by the dashed line at 45° .
- Fig. 3 The decay missing mass squared distribution for the $\Sigma^+ \rightarrow p\pi^0$ (open) and $\Sigma^+ \rightarrow p\gamma$ (shaded) samples, for events with $\delta MM^2 \leq 0.005 \text{ GeV}^2$. The dashed line shows the events having $\delta MM^2 \leq 0.004 \text{ GeV}^2$.
- Fig. 4 Distribution of the cosine of the angle between Σ^+ polarization and decay proton directions in the Σ^+ rest frame for the (a) $\Sigma^+ \rightarrow p\pi^0$ and (b) $\Sigma^+ \rightarrow p\gamma$ events having $\delta MM^2 \leq 0.005 \text{ GeV}^2$.

FIG. 1

FIG. 2

FIG. 3

FIG. 4